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Air Force Institute Of Technology

Feasibility Study of Variance Reduction in the THUNDER Campaign Level Model

Capt Earl M. Bednar

Military Operations Research Society Symposium

22 June 2005

Educating The World's Best Air Force!

Overview

- Objective
- THUNDER
- Methodology
- Analysis
- Conclusions

Objective

- Problem:
  - Chief of Staff of the Air Force (CSAF)
  - Air Force Studies and Analysis Agency (AFSAA)
  - Request an effective & efficient method to reduce the variance in the results of THUNDER

- Answer:
  - Control Variates
  - Common Random Numbers
  - Antithetic Variates

THUNDER

- Air Force Standard Analysis Toolkit (AFSAT)
- Campaign-level joint military operations
- Written in CACI's SIMSCRIPT II.5
  - English like programming language
- >1,500 source files
- >360,000 lines of code
- 254 random inputs

Overview

- Objective
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- **Methodology**
  - **Common Random Numbers**
  - **Control Variates**
- Analysis
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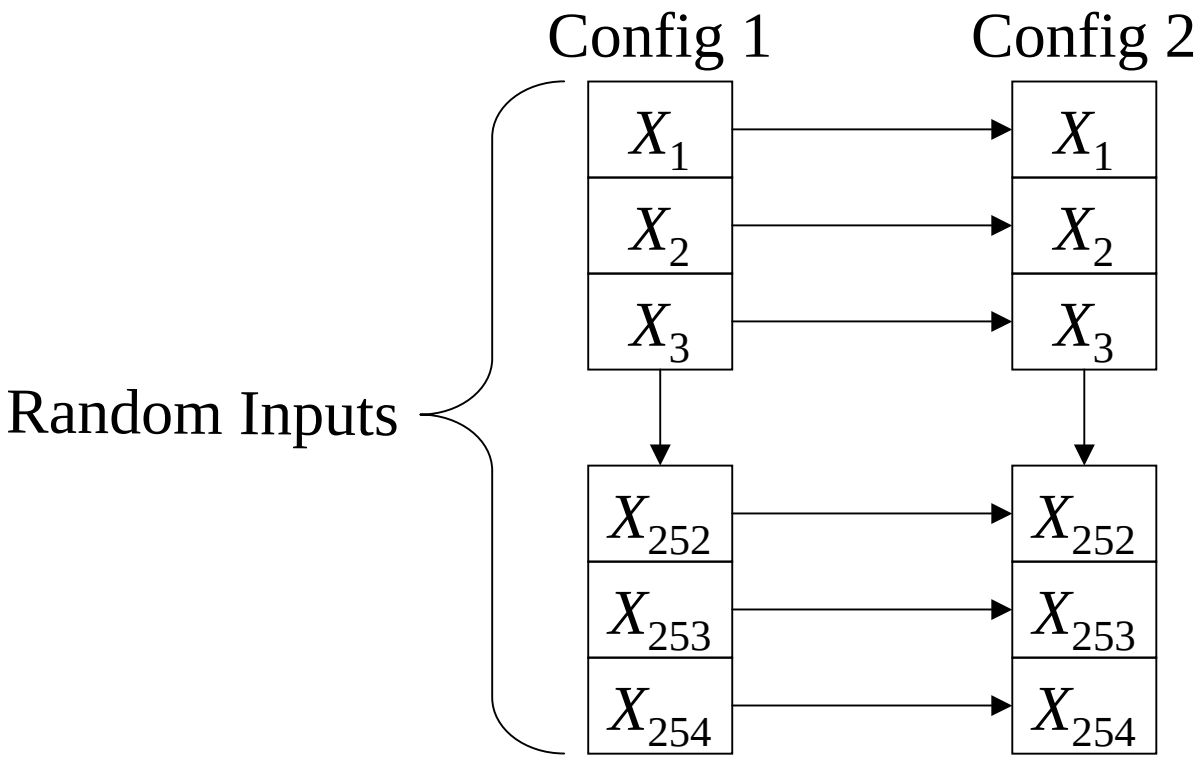
Common Random Numbers

- Synchronization

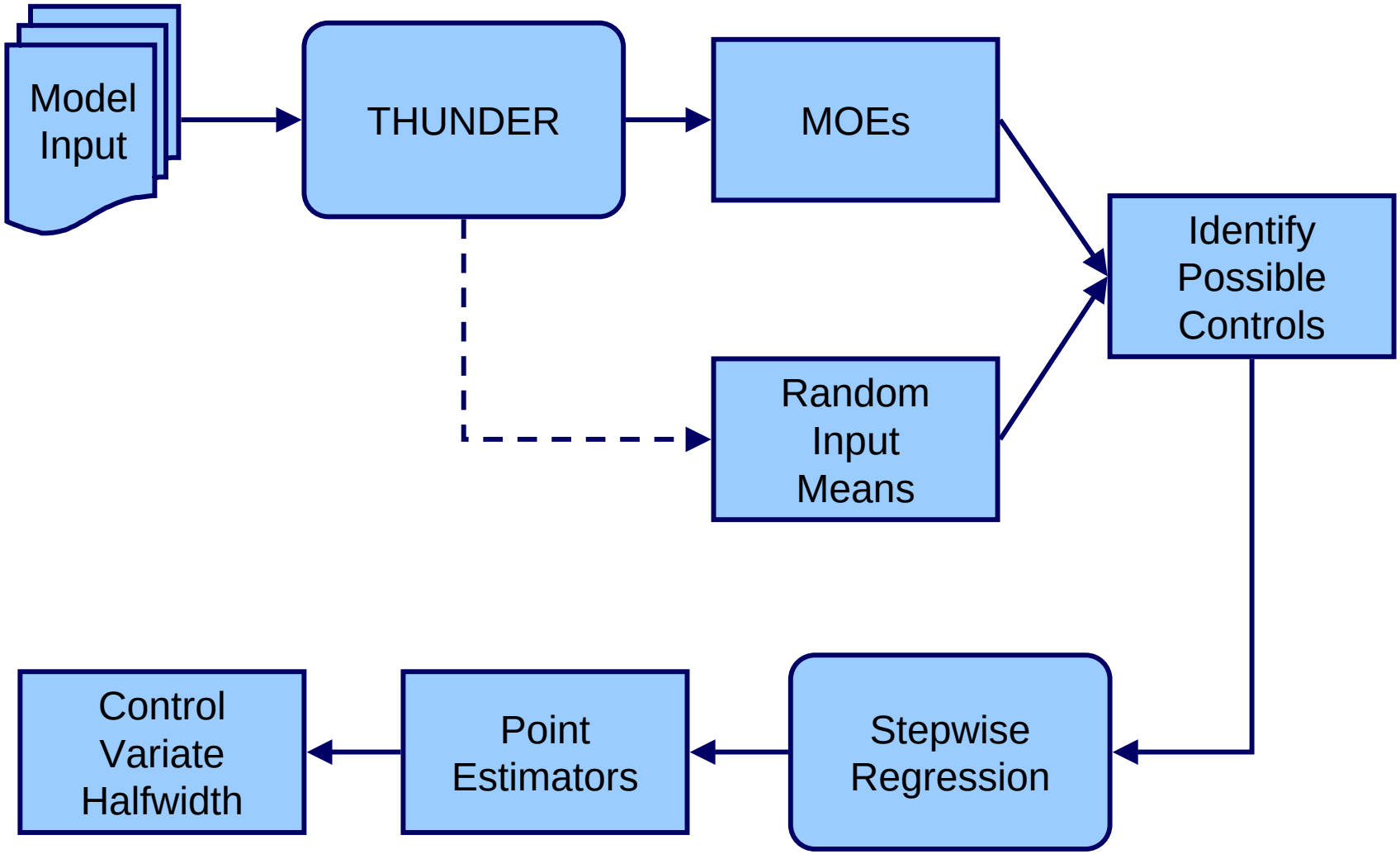


- Problem with current RNG
  - 254 random variates and only 10 streams

Random Number Generator

- MRG32k3a
- Developed by
  - Pierre L'Ecuyer
    - U. de Montréal
  - Richard Simard
    - U. de Montréal
  - E. Jack Chen
    - BASF Corp.
  - W. David Kelton
    - U. of Cincinnati
- Linear Congruential Generator
  - period 1.6×10^{7} to 2.8×10^{14} elements
- Combined Multiple Recursive Generator
  - 1.8×10^{19} streams
    - 1.7×10^{38} elements
- Programmed in C and Java
  - Streams, Antithetics, Seeds

Control Variates Flow Chart



Overview

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  - **Common Random Numbers**
  - **Control Variates**
  - **Random Number Generator**
- Conclusions

Measures Of Effectiveness

- 20 MOEs
  - Flown per Planned Sortie
  - Losses per Sortie
  - Square Miles Gained
- 4 Levels of Aggregation
  - Force
  - Base
  - Squadron
  - System

Experimental Runs

- 8 separate run configurations
  - 30 Replications each
  - 240 Total Replications
  - ASC Major Shared Resource Center

SET	RNG (NEW/OLD)	SYNCHRONIZED (YES/NO)	ANTITHETIC (YES/NO)	COLLECT CV (YES/NO)	CONFIGURATION (ORIGINAL/MODIFIED)
A	OLD	NO	NO	YES	ORIGINAL
B	NEW	NO	NO	NO	ORIGINAL
C	NEW	NO	NO	YES	MODIFIED
D	NEW	YES	NO	YES	ORIGINAL
E	NEW	YES	NO	YES	MODIFIED
F	NEW	YES	YES	YES	ORIGINAL
G	OLD	NO	NO	NO	ORIGINAL
H	NEW	YES	NO	NO	ORIGINAL

Common Random Numbers

- Reduction
  - 10 of 19
- No patterns

MOE	BASE HALFWIDTH	SYNCHRONIZED HALFWIDTH	PERCENT CHANGE
A-10 LPS	0.001940153	0.001590769	-18.01%
A-6 LPS	0.005187968	0.003856901	-25.66%
BLUE FPS	0.010247512	0.008539409	-16.67%
BLUE LPS	0.000770395	0.000659791	-14.36%
BLUE SMG	401.9576399	357.5307451	-11.05%
DHAHRAN FPS	0.029904287	0.027359177	-8.51%
F-15 LPS	0.001401777	0.001609386	14.81%
FA-18 FPS total	0.016106877	0.01672975	3.87%
FA-18 FPS DCA	0.005501239	0.004594474	-16.48%
MIG-23 LPS	0.032332763	0.024092911	-25.48%
MIG-29 LPS	0.027652343	0.030965238	11.98%
MIRAGE FPS total	0.017106674	0.025227701	47.47%
MIRAGE FPS INT	0.029598399	0.030482717	2.99%
MIRAGE LPS	0.01957014	0.015011175	-23.30%
MUDAYSIS FPS	0.016871397	0.017668922	4.73%
RED FPS	0.006272345	0.006833599	8.95%
RED LPS	0.005909479	0.007268262	22.99%
RIYADH FPS	0.006359085	0.005819308	-8.49%
SHAIBAH FPS	0.034021777	0.040368895	18.66%

Control Variates

MOE	REPLICATION HALFWIDTH	CV HALFWIDTH	PERCENT CHANGE	EQUIVALENT REPLICATIONS
A-10 LPS	0.00075445	0.000159564	-78.85%	607
A-6 LPS	0.003489524	0.002120285	-39.24%	77
BLUE FPS	0.009062548	0.007242324	-20.09%	46
BLUE LPS	0.000561401	0.00033589	-40.17%	79
BLUE SMG	268.0705303	236.1766719	-11.90%	38
DHAHRAN FPS	0.031932469	0.024634985	-22.85%	49
F-111 LPS	0.001710663	0.000817956	-52.18%	121
F-15 LPS	0.000969011	0.000627455	-35.25%	68
FA-18 FPS total	0.016933126	0.015413409	-8.97%	36
FA-18 FPS DCA	0.003428121	0.003311208	-3.41%	32
MIG-23 LPS	0.020114382	0.020331007	1.08%	30
MIG-29 LPS	0.026351157	0.022059499	-16.29%	42
MIRAGE FPS total	0.015716995	0.013363553	-14.97%	41
MIRAGE FPS INT	0.022547304	0.013958327	-38.09%	74
MIRAGE LPS	0.014436042	0.013046527	-9.63%	37
MUDAYSIS FPS	0.013106485	0.012044326	-8.10%	35
RED FPS	0.004319957	0.003268615	-24.34%	51
RED LPS	0.005896852	0.005145653	-12.74%	39
RIYADH FPS	0.006054193	0.004081502	-32.58%	63
SHAIBAH FPS	0.022973304	0.016907879	-26.40%	53

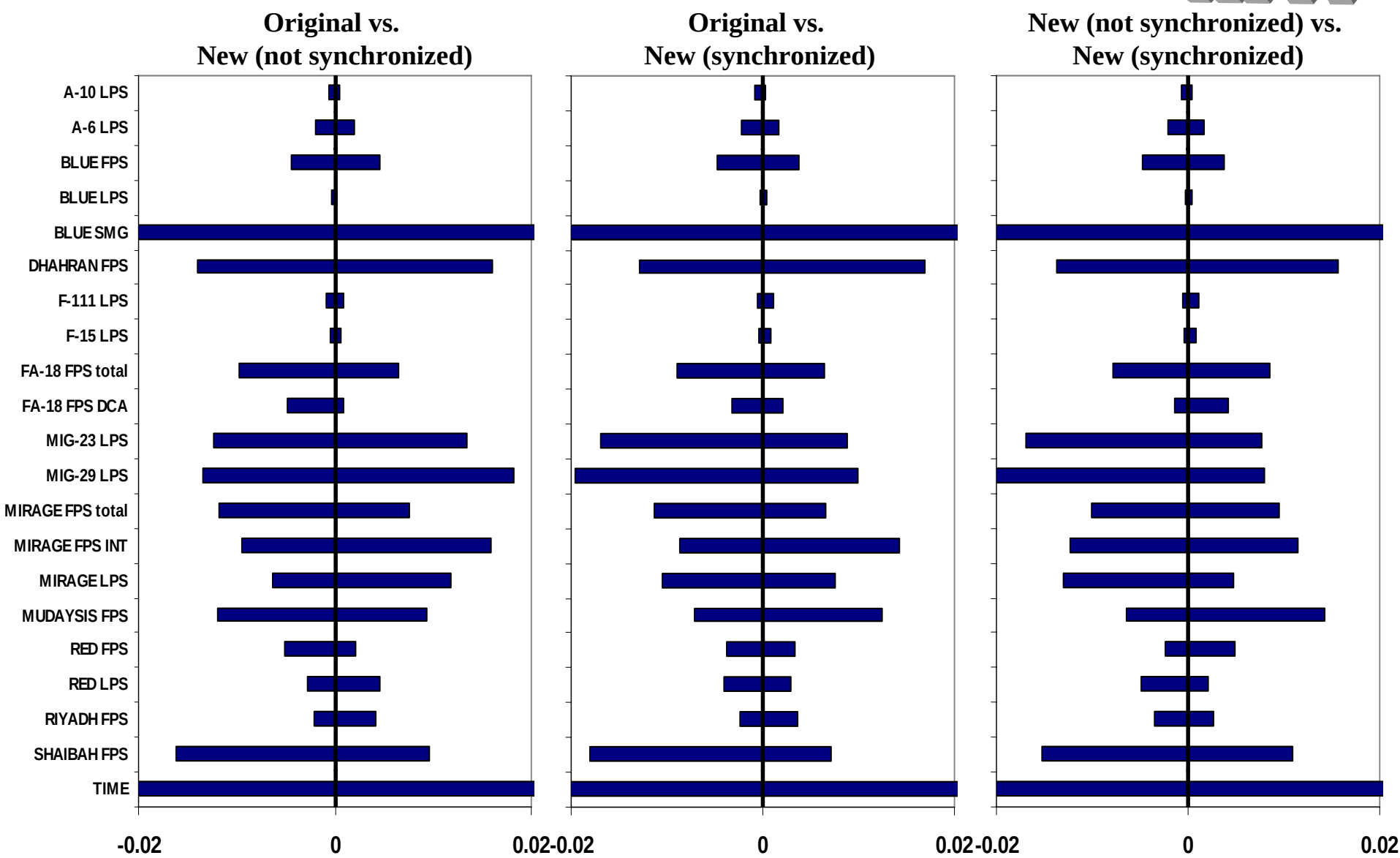
Control Variates

MOE	WEIGHT	CONTROL	MOE	WEIGHT	CONTROL
A-10 LPS	-0.0002	__AIR060_2	MIG-23 LPS	-6.6526	__ADF121_2
A-6 LPS	-0.0071	__AIR050_2		0.1433	__AIR101_1
	-0.0759	__ISR000_4	MIG-29 LPS	0.6471	__AIR528_1
BLUE FPS	-0.0722	__AIR050_1		-1.4314	__BSE050_1
	-0.0659	__AIR070_2		-0.2311	__GRD095_1
	-0.0035	__AIR800_3		-0.7147	__ISR000_4
	0.3282	__BSE400_1	MIRAGE FPS total	-0.3242	__ADF150_1
	46.8237	__PLA443_1		0.5198	__AIR561_1
	0.6659	__UTL104_1		0.0855	__AIR602_1
BLUE LPS	0.0101	__ADF150_2	MIRAGE FPS INT	-3.3544	__ADF121_1
BLUE SMG	-23825.1823	__ADF105_1		7.9362	__ADF121_2
	40.5388	__AIR060_2		0.0101	__AIR800_3
	3649.5981	__AIR101_2		-1.0679	__BSE003_2
	-1408.6753	__AIR561_2		106.4336	__PLA443_1
	-20765.0668	__AIR840_1	MIRAGE LPS	-2.3615	__ADF121_1
	-27766.1967	__AIR840_2	MUDAYSIS FPS	-0.2438	__ADF150_2
	-8446.2005	__BSE400_1		-0.0089	__AIR800_3
DHAHRAN FPS	-0.1779	__AIR050_1		0.1621	__GRD095_2
	-0.2230	__AIR070_2	RED FPS	0.6949	__BSE200_5
	0.9677	__BSE400_1	RED LPS	0.0922	__ADF150_1
F-111 LPS	0.0213	__ADF150_2		-0.0629	__AIR070_2
	-0.0120	__AIR060_1		0.6117	__UTL104_1
	-0.1221	__BSE200_5	RIYADH FPS	-0.2501	__AIR007_1
F-15 LPS	0.0069	__AIR050_1		-0.0395	__AIR101_1
	0.0019	__AIR050_2		-0.0621	__AIR101_2
FA-18 FPS total	0.0252	__AIR050_2		-0.0505	__GRD095_1
	-0.0889	__AIR070_2	SHAIBAH FPS	-0.1675	__AIR101_1
	-1.3057	__AIR810_2		1.3115	__BSE003_1
FA-18 FPS DCA	1.4195	__ADF121_3			
	0.0006	__AIR060_2			

BLUE Square Miles Gained

CONTROL	WEIGHT	MODULE PURPOSE	SPECIFIC DRAW PURPOSE
ADF105_1	-23825.18	Used to calculate the flight groups position, altitude, speed, average location, and delivery profile.	Used to check for point on battlefield. .INTERVIS.ANGLE = (Distribution) / RADIAN.C
AIR060_2	40.54	Manages defensive anti tactical ballistic missile mission detections and engagements.	Used in setting saturation delay on shooter. (Distribution)
AIR101_2	3649.60	Sets up and air engagement by creating and air-to-air engagement for each flight to be used for storing computations.	Used in determining the engagement probability. (.prob.engage < U(0,1))
AIR561_2	-1408.68	Determines if, having arrived at the target's estimated coordinate, the flight group can find the target.	Determines the success of a mid-course update. (U(0,1)<= .best.prob)
AIR840_1	-20765.07	Determines the number of target elements that are destroyed when a given weapons area of effect fully or partially covers a target.	Determine whether a live target element is hit. (U(0,1)<.prob.hit.live)
AIR840_2	-27766.20	Determines the number of target elements that are destroyed when a given weapons area of effect fully or partially covers a target.	Determine whether a live target element is hit. (U(0,1)<.exp.live.hits)
BSE400_1	-8446.20	Determine s the availability of aircraft, establishes the munition configurations, allocates fuels and determines whether to cancel or run the mission as scheduled.	Determines the cancellation of a sortie due to degrade. (U(0,1)<eawp.sortie.degrade)

Random Number Generator



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Conclusions

- Common random numbers
  - Generally synchronize
  - Need new random number generator
  - Will not always result in reduction
- Control variates
  - Always reduction
  - Better estimates with less replications
  - Good insight
  - Able to be automated
- Both methods are applicable to STORM

QUESTIONS?

Thank You

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